Subtropical cirrus cloud extinction to backscatter ratios measured by Raman Lidar during CAMEX-3

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[1] The NASA/GSFC Scanning Raman Lidar was stationed on Andros Island, Bahamas for the third Convection and Moisture Experiment (CAMEX 3) held in August–September, 1998 and acquired an extensive set of cirrus cloud measurements [*Whiteman et al.*, 2001]. Distinct differences in the optical properties of the clouds are found when the cirrus are hurricane-induced versus non-hurricane-induced. Hurricane-induced cirrus clouds are found to generally possess lower values of extinction-to-backscatter ratio (S) than non-hurricane-induced clouds. Comparison of the S measurements made here with those of other studies reveal at times large differences. Given that S is often a required parameter for space-based retrievals of cloud optical depth using backscatter lidar, these large differences in S measurements imply difficulties in developing a parameterization of S for use in space-based lidar retrievals. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0360 Atmospheric Composition and Structure: Transmission and scattering of radiation; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Whiteman, D. N., B. Demoz, and Z. Wang (2004), Subtropical cirrus cloud extinction to backscatter ratios measured by Raman Lidar during CAMEX-3, *Geophys. Res. Lett.*, *31*, L12105, doi:10.1029/2004GL020003.

1. Introduction

[2] Cirrus clouds affect the earth's radiation budget strongly by influencing both the greenhouse effect and planetary albedo [*Liou*, 1986] and can create errors in satellite retrievals. The study of *McFarquher et al.* [2000] showed that tropopause tropical cirrus clouds with optical depths of 0.01 have corresponding heating rates and cloud radiative forcing of 1.66 K day^{-1} and 1.6 W m^{-2}, respectively. Cloud climatology studies based on SAGE II observations [*Wang et al.*, 1996] have indicated frequencies of sub-visual cirrus (optical depths below ~0.03) near the tropical tropopause of up to 70% indicating that the radiative effects of cirrus clouds are very large in tropical locations.

[3] Space-based lidar offers great potential for acquiring accurate global statistics on cloud heights and optical depths. However, due to the presence of multiple scattering and tropospheric aerosols, the retrieval of cirrus cloud optical depth from space-based lidar will under many circumstances require an accurate parameterization of the extinction-to-backscatter ratio for cirrus clouds. This parameterization may be a function of geographic location and/or cirrus type. Therefore, studies of the cirrus extinction-to-backscatter ratio are needed in differing geographic locations. Mid-latitude cirrus cloud properties have been extensively studied using lidar, cloud radar and radiometers [*Platt et al.*, 1987; *Mace et al.*, 2001; *Sassen and Comstock*, 2001; *Wang and Sassen*, 2002; *Sakai et al.*, 2003] but corresponding measurements in tropical or sub-tropical areas, where cirrus occurrences frequencies are high, are more limited [*Sassen et al.*, 2000; *Platt et al.*, 1998; *Comstock et al.*, 2002; *Immler and Schrems*, 2002] and none of those studies has made use of Raman scattering measurements.

2. Raman Lidar Measurements of Cirrus Clouds

[4] Raman Lidar systems have proven very useful at quantifying cirrus cloud optical depth and extinction-to-backscatter ratio [*Ansmann et al.*, 1992; *Reichardt et al.*, 2002; *Whiteman et al.*, 2001; *Sakai et al.*, 2003] even in the presence of multiple scattering [*Eloranta*, 1998; *Reichardt et al.*, 2000; *Whiteman et al.*, 2001]. The unique advantage of a lidar system that measures pure molecular scattering such as a Raman or High Spectral Resolution Lidar [*Eloranta*, 2000] is that the cirrus cloud extinction-to-backscatter ratio (S in units of sr) can be determined directly without the use of inversion [*Klett*, 1981]. To our knowledge the current work is the only study of cirrus cloud properties made in a sub-tropical or tropical location using either a Raman or High Spectral Resolution Lidar (HSRL).

3. The NASA/GSFC Scanning Raman Lidar (SRL) in CAMEX-3

[5] During July–September, 1998 the NASA/GSFC Scanning Raman Lidar (SRL) was stationed on Andros Island (24.7N, −77.75W) in the Bahamas as a part of the third Convection and Moisture Experiment (CAMEX-3). Though the main goal of the SRL participation in CAMEX-3 was to acquire detailed water vapor measurements during hurricane season, the system also provided high quality measurements of cirrus clouds. The cirrus cloud extinction-to-backscatter ratio derived from approximately 220 hours of SRL cloud measurements are studied here.

[6] The SRL is a mobile lidar system designed to detect light backscattered at the laser wavelength by molecules and aerosols as well as Raman-backscattered light from water vapor, nitrogen, and oxygen molecules. The measurements

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